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Effect of Longitudinal Grooves on Survivability of Cylindrical Steel Projectiles Fired Against Simulated Concrete Targets

by
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NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

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FOREWORD

The research described in this report was conducted in support of the controlled fragmentation studies for hard target penetrator warheads. This effort was supported by the Naval Air Systems Command (NAVAIR) and executed by the Naval Weapons Center (NWC) under the Strike Warfare Weaponry Technology Block Program under Work Request 21104, AIRTASK A03W-03P2/008B/2F32-300-000 (appropriation 1721319.41AJ). This airtask provides for continued exploratory development in the air superiority and air-to-surface mission areas. Mr. H. Benefiel, AIR-350, was the cognizant NAVAIR Technology Administrator.

This report has been reviewed for technical accuracy by John Pearson, Detonation Physics Division, Research Department.

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(U) *Effect of Longitudinal Grooves on Survivability of Cylindrical Steel Projectiles Fired Against Simulated Concrete Targets*, by O. E. R. Heimdahl and J. C. Schulz. China Lake, Calif., Naval Weapons Center, November 1982. 30 pp. (NWC TP 6402, publication UNCLASSIFIED.)

(U) Small hollow, cylindrical steel projectiles containing longitudinal grooves on the inner surface were fired against simulated concrete targets. These firings complement earlier firings of projectiles containing circumferential grooves. The grooves in both cases were intended to simulate the stress-raising effects of warhead shear-control grids. Some projectiles were filled with an explosive simulant, while others were left unfilled.

(U) All projectiles tested developed a bulge near the front of the internal cavity. This can be termed the primary failure zone. The presence of longitudinal grooves in this region reduced the survival velocity, while grooves located a short distance to the rear had no effect. The reduction in survival velocity for projectiles with longitudinal grooves was less than for projectiles with circumferential grooves of the same depth. Significant differences between the deformation and failure behavior of the filled and unfilled projectiles were observed.

(U) From the standpoint of warhead design, the conclusion to be drawn from this work is that a shear-control grid can be machined into the case of a penetrator warhead without affecting its survivability providing that the grid is not allowed to extend into the primary failure zone.

CONTENTS

INTRODUCTION

A variety of methods are available for fragmentation control in warhead cases. These include potted fragments, notched wire wraps, textured insert liners, and shear-control grids. All of these methods have been used successfully in airburst warhead designs to produce fragments of prescribed sizes and shapes. Not all, however, are suitable for use in penetrator warheads intended to defeat hard or moderately hard targets. Cases with potted fragments or notched wire wraps are too weak to survive the severe loads present during target impact. Textured insert liners, while they do not weaken the case, may not provide sufficient precision for some applications.

Pearson's shear-control method,[1] consisting of a shallow grid system machined onto the inner surface of the warhead case (Figure 1), appears to offer a desirable combination of precise control and reasonable structural strength. There is concern, however, that these stress-raising grooves may act to degrade warhead survivability. This concern led the authors to investigate, through small projectile firings and finite element computer modeling, the possible deleterious effects of shear-control grooves on warhead survivability.

In the previously reported studies,[2,3] a single circumferential groove in the cavity wall was used to approximate the stress-raising effects of a shear-control grid. Test firings of flat-fronted steel cylinders with a hemispherically-fronted internal cavity containing such a groove were made at normal incidence against simulated concrete and steel plate targets. The location and depth of the groove were varied. Finite element analyses of the response of circumferentially grooved projectile cases subjected

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[1] John Pearson. "The Shear-Control Method of Warhead Fragmentation," in *Proceedings of the Fourth International Symposium on Ballistics, Monterey, Calif., 17-19 Oct 1978.* Monterey, Calif., Navy Postgraduate School, 1978. (Publication UNCLASSIFIED.)

[2] Naval Weapons Center. *Survivability of Penetrators With Circumferential Shear-Control Grooves,* by J. C. Schulz and O. E. R. Heimdahl. China Lake, Calif., NWC, April 1981. 28 pp. (NWC TP 6275, publication UNCLASSIFIED.)

[3] ------. *Survivability Analysis for Impacting Warheads With Shear-Control Grids,* by Olaf E. R. Heimdahl and John Pearson. China Lake, Calif., NWC, February 1982. 40 pp. (NWC TP 6288, publication UNCLASSIFIED.)

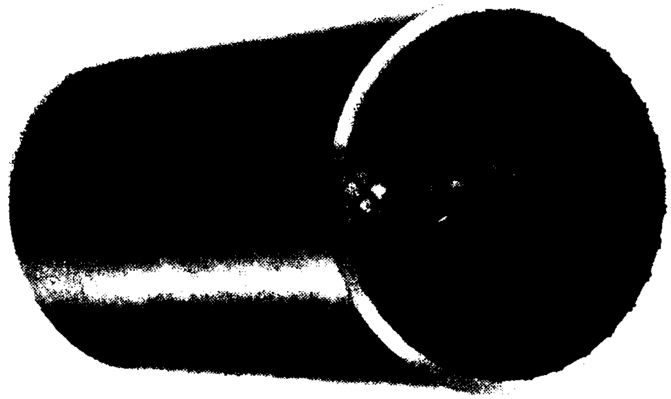


FIGURE 1. Shear-Control Grid Machined into Inner Surface of Warhead Case.

to impact loads were used to help interpret the results. These studies showed that the effects of circumferential grooves on survival velocity depend on the failure mode of the ungrooved projectile, on the placement of the groove, and on the groove depth.

Differences in behavior between projectiles fired against simulated concrete and steel plate targets were observed. For penetration into simulated concrete, the primary failure zone occurred near the front of the internal cavity where a bulge developed (Figure 2). A circumferential groove in this region had a detrimental effect on projectile survivability, an effect which increased with increasing groove depth. A groove to the rear of the primary failure zone, although it resulted in a characteristic ring deformation pattern at the groove location, had a negligible effect on survival velocity. For perforation of steel plates, damage was confined largely to the front end of the projectile, and a circumferential groove did not affect the survival velocity. The ring deformation pattern at the groove was again present (Figure 3).

Shear-control grids usually contain longitudinal as well as circumferential components. Indeed, grids designed to produce rod-shaped fragments consist predominately of longitudinal or nearly longitudinal grooves. Just as a circumferential groove acts to enhance circumferential fracturing, longitudinal grooves might be expected to enhance longitudinal fracturing. Such enhancement should be especially evident in filled projectiles, where the hydrostatic pressure exerted by the filler on the case results in higher hoop stresses. It is natural, therefore, to investigate the effects of longitudinal as well as circumferential grooves on survivability.

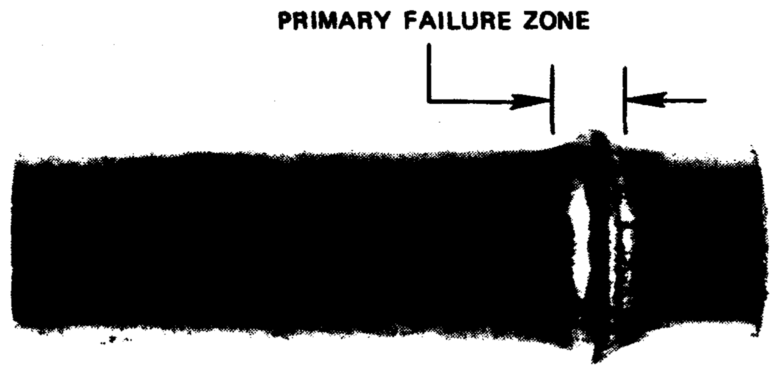


FIGURE 2. Primary Failure Zone for Projectile with Circumferential Groove Located at Point of Maximum Bulging Fired Against Thorite Target.

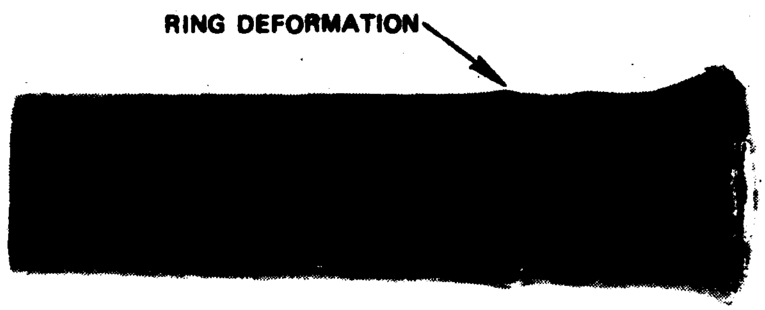


FIGURE 3. Ring Deformation Caused by Circumferential Groove Located to the Rear of Cavity Bulge in Projectile Fired Against Steel Plate Target.

In the present study, firings were made of both filled and unfilled projectiles against simulated concrete targets at normal incidence. Finite element modeling of projectiles with longitudinal grooves is not possible using a two-dimensional code because of the lack of axisymmetry. Thus, while reference will be made to finite element results for ungrooved projectiles, the current study is primarily experimental.

DESCRIPTION OF EXPERIMENTS

PROJECTILES

The projectiles were flat-fronted steel cylinders, 2 inches long and 0.5 inch in diameter, with a hemispherically-fronted internal cavity. The front of the cavity was 0.25 inch from the front end of the projectile, and the cavity wall thickness was 0.04 inch. Eight longitudinal grooves, equally spaced around the circumference, were machined into the surface of the cavity. The grooves were 0.008-inch deep and started either 0.46 or 0.71 inch from the front end of the projectile. Except for differences in the grooves, the projectiles were the same as those used for circumferential groove firings. Counting ungrooved projectiles, there were three different configurations as shown in Figure 4. The projectiles were machined from 4340 steel rods and were heat-treated to a 38-40 Rockwell "C" hardness, an acceptable hardness for a warhead case with a shear-control grid.

FILLER

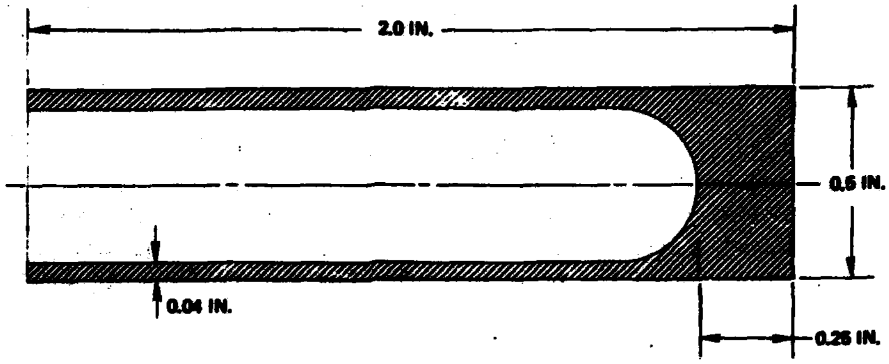
The internal cavities of some of the projectiles were filled with plasticine (a wax-based modeling material), while the remainder were left unfilled. Plasticine is mechanically similar to some explosives and thus makes good explosive simulant. It was anticipated that the presence of filler in the internal cavity would result in higher hoop stresses in the cavity wall which, in turn, would lead to fracturing of the longitudinal grooves. Comparisons could then be made not only between longitudinal and circumferential grooves, but also between filled and unfilled projectiles.

TARGETS

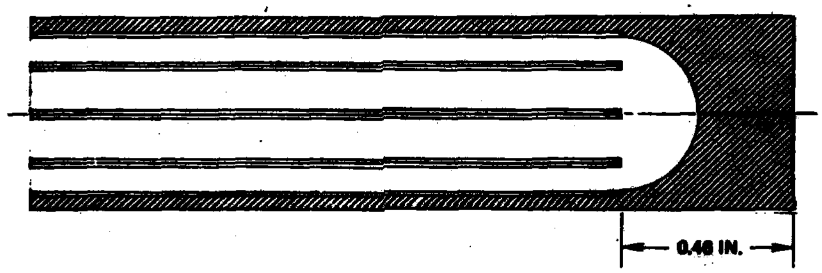
The simulated concrete targets were made of Thorite (trademark of Standard Dry Wall Products), a fast-setting, high-strength (3,950 psi compressive strength) concrete patching compound consisting of sand, cement, and additives to promote rapid curing. Consistency in target preparation is critical for assuring high strength and uniformity among targets. The procedure used is described in Appendix A of the reference cited as footnote 2.

TEST PROCEDURE

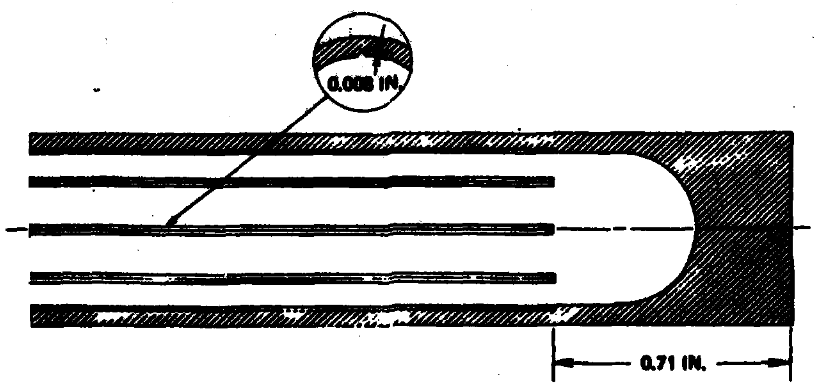
The projectiles were fired from a smooth-bore, 50-caliber powder gun and impacted the targets at normal incidence. The targets were placed 18 inches from the end of the barrel. Impact velocities were measured in the gun barrel with a photo



(a) No grooves.



(b) Grooves starting 0.46 inch from front end.



(c) Grooves starting 0.71 inch from front end.

FIGURE 4. Cross-sectional Views of Longitudinally Grooved Test Projectiles.

diode system coupled to an interval counter. The apparatus is described more fully by Schulz, et al.[4]

EXPERIMENTAL RESULTS

Thirty-two projectiles were fired. Of these, 19 were filled and 13 were unfilled. Impact velocities ranged from 2,090 to 2,770 ft/s. The results are summarized in Table 1. Photographs of the projectiles after test are shown in Appendix A.

CASE DEFORMATION

Although both filled and unfilled projectiles bulged near the front of the internal cavity, the bulge profiles clearly differ (Figures A-1a versus A-4b, for example). Bulges in the filled projectiles are more rotund and extend for a greater distance axially along the wall. The more localized bulges in the unfilled projectiles tend to produce a hinge-like collapse near the failure limit. No axial ridges at the longitudinal groove locations analogous to the ring deformations associated with the circumferential grooves were observed. (While the case is compressed axially, it is expanded radially; thus circumferential rings were formed while longitudinal ridges were not.)

The increase in case diameter at the bulge and the decrease in projectile length are plotted as functions of impact velocity in Figures 5 and 6, respectively. Also shown are theoretical curves obtained for unfilled, ungrooved projectiles by finite element analysis using the method described by Stronge and Schulz.[5] The experimental points for the unfilled projectiles generally fall on or slightly below the theoretical curves, while the points for the filled projectiles lie above the curves. The higher values for the filled projectiles reflect the greater impact energies and the hydrostatic pressure due to the presence of a cavity material. The increase in diameter at the nose is plotted versus impact velocity in Figure 7. This increase does not appear to depend on the presence or absence of filler or on whether or not the projectile survived.

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[4] J. C. Schulz, J. Pearson, O. E. R. Heimdahl, and S. Finnegan. "Effect of Shear-Control Grids on the Survivability of Penetrator Warheads," in *Proceedings of the Sixth International Symposium on Ballistics, Orlando, Fla., 27-29 Oct 1981*. Columbus, Ohio, Battelle Columbus Laboratories, 1981. (Publication UNCLASSIFIED.)

[5] W. J. Stronge and J. C. Schulz. "Projectile Impact Damage Analysis," in *Proceedings of the Symposium on Computational Methods in Nonlinear Structural and Solid Mechanics, Arlington, Va., 6-8 Oct 1980*. Published as special issue of *J. Computers and Structures*, Vol. 13, No. 1-2 (1981), pp. 287-294.

TABLE 1. Results of Firings Against Thorite Targets.

Groove location, in.	Round no.	Empty mass, grams	Filled mass, grams	Velocity, ft/s	Result	Penetration, in.	Final nose diameter, in.	Final bulge diameter, in.	Final length, in.	Remarks
None	13	19.71	Unfilled	2,390	Survived	3.1	0.514	0.615	1.897	Small cracks in bulge.
None	14	19.70		2,460	Survived	3.4	0.521	0.598	1.903	Bulged.
None	12	19.72		2,460	Failed	2.7	0.524	. . .	. . .	Sheared off at bulge.
0.46	18	19.60		2,370	Survived	3.0	0.514	0.600	1.913	Bulged.
	22	19.88		2,400	Survived	3.1	0.518	0.601	1.910	Bulged.
	21	20.01		2,460	Failed	2.5	0.522	. . .	. . .	Sheared off at bulge.
	20	19.64		2,480	Failed	2.4	0.525	. . .	. . .	Sheared off nose, peeled case.
	19	20.12		2,480	Failed	3.4	0.525	. . .	. . .	Sheared off at bulge.
0.71	29	19.73		2,420	Survived	3.3	0.515	0.618	1.887	Canted nose, small cracks on bulge.
	30	19.70		2,480	Survived	3.5	0.517	0.615	1.890	Slightly canted nose.
	31	19.87		2,510	Survived	3.6	0.518	0.608	1.895	Bulged.
	32	19.59		2,520	Survived	3.7	0.517	0.614	1.891	Bulged.
	28	19.71		2,520	Failed	2.9	0.521	. . .	. . .	Sheared off at nose.
None	3	19.90	26.44	2,275	Survived	4.7	0.512	0.585	1.930	Rounded bulge.
	11	19.98	26.55	2,370	Survived	4.2	0.516	0.640	1.886	Large rounded bulge.
	16	22.10	28.12	2,380	Survived	4.0	0.516	0.635	1.883	Overweight
	15	20.01	26.40	2,380	Survived	4.9	0.519	0.631	1.905	Rounded bulge.
	5	19.87	26.48	2,390	Failed	3.2	0.520	. . .	. . .	Split case, nose attached.
	4	19.85	26.44	2,490	Failed	3.5	0.519	. . .	. . .	Split case, nose attached.
	2	19.92	26.52	2,600	Failed	3.2	0.524	. . .	. . .	Split case, nose detached.
	1	19.89	26.58	2,770	Failed	3.3	0.533	. . .	. . .	Split case, nose detached.
0.46	8	19.94	26.58	2,090	Survived	4.0	0.509	0.550	1.955	Moderate rounded bulge.
	9	20.04	26.58	2,180	Survived	3.3	0.511	0.573	1.941	Rounded bulge.
	10	19.81	26.45	2,260	Failed	3.0	0.519	. . .	. . .	Split case, nose attached.
	17	19.94	26.51	2,280	Failed	3.2	0.521	. . .	. . .	Split case.
	7	19.91	26.48	2,290	Failed	3.6	0.514	. . .	. . .	Split case.
	6	19.94	26.55	2,360	Failed	3.6	0.514	. . .	. . .	Split case.
0.71	26	19.85	26.50	2,205	Failed	3.6	0.512	. . .	. . .	Split case.
	24	19.84	26.44	2,220	Survived	4.0	0.511	0.583	1.935	Rounded bulge.
	27	19.86	26.50	2,270	Survived	4.6	0.509	0.576	1.940	Rounded bulge.
	25	19.73	26.21	2,320	Failed	3.4	0.514	. . .	. . .	Split case, nose attached.
	23	19.72	26.17	2,360	Failed	2.7	0.515	. . .	. . .	Split case, nose detached.

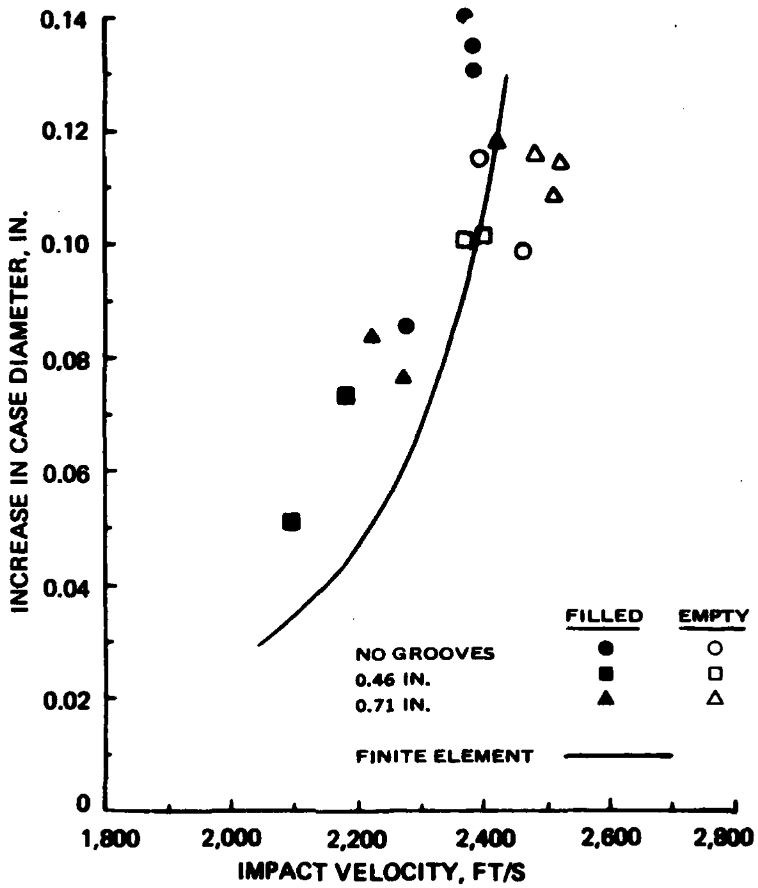


FIGURE 5. Increase in Case Diameter at Bulge vs. Impact Velocity for Projectiles Fired Against Simulated Concrete. Projectiles had either no grooves or longitudinal grooves starting 0.46 or 0.71 inch from nose.

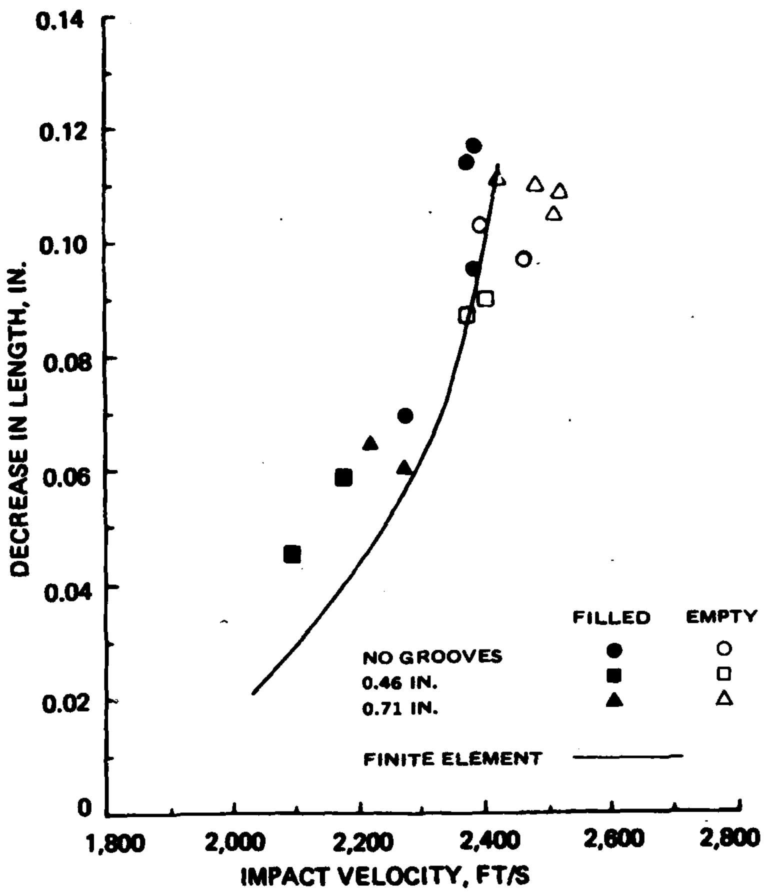


FIGURE 6. Decrease in Length vs. Impact Velocity for Projectiles Fired Against Simulated Concrete. Projectiles had either no grooves or longitudinal grooves starting 0.46 or 0.71 inch from nose.

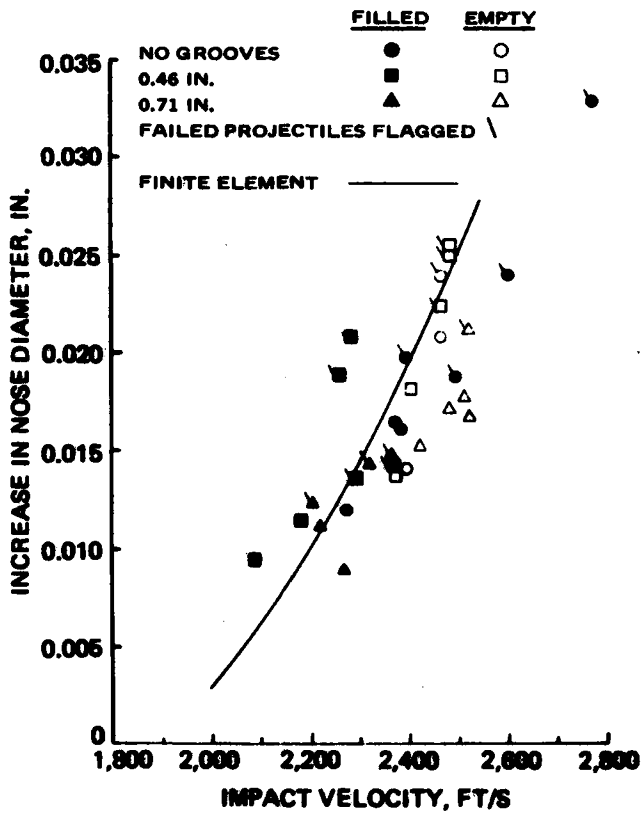


FIGURE 7. Increase in Nose Diameter vs. Impact Velocity for Projectiles Fired Against Simulated Concrete. Projectiles had either no grooves or longitudinal grooves starting 0.46 or 0.71 inch from nose.

CASE FAILURE

All unfilled projectiles that failed fractured circumferentially at the cavity bulge (Figure A-1c, for example). Subsequent gross deformation of the case occurred as the separated nose section was forced into the remaining portion of the case. In contrast, all of the filled projectiles that failed fractured longitudinally such that the case was split open down the side (Figure A-4e, for example). Some circumferential fracturing at the bulge was also present. In filled projectiles with longitudinal grooves, the split in the case usually followed one of the grooves. The longitudinal fractures appear to be tensile in character. Near the rearward end of the fracture edges tend to become non-normal to the surface, perhaps reflecting some tearing action.

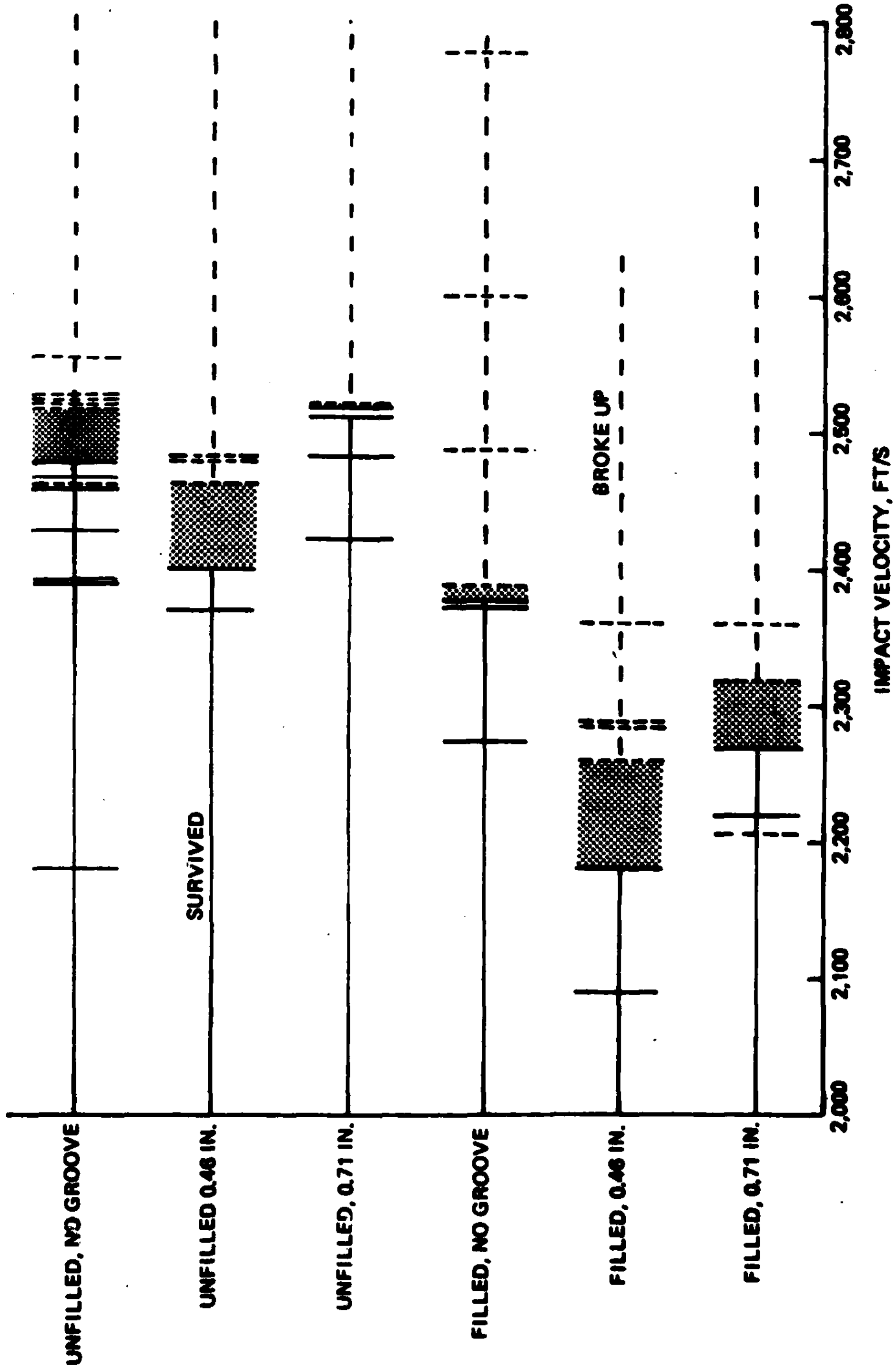


FIGURE 8. Impact Behavior of Projectiles Fired Against Simulated Concrete Targets. Projectiles had either no grooves or longitudinal grooves starting 0.46 or 0.71 inch from nose.

SURVIVAL VELOCITY

The survival behavior of the various projectile configurations over the range of firing velocities is shown in Figure 8. Results from previous firings of unfilled, ungrooved projectiles are included.[2] The solid vertical lines denote projectiles that survived, while the dashed vertical lines denote projectiles that broke up. The greyed areas indicate intervals of uncertainty in estimating the survival velocity (the velocity below which projectiles survive and above which they fail).

Filled projectiles failed at lower velocities than unfilled projectiles of the same configuration. The reduction in survival velocity due to filler was 5.4% for ungrooved projectiles and 8.6 and 8.9% for projectiles with longitudinal grooves beginning 0.46 and 0.71 inch from the nose, respectively.

In previous firings a circumferential groove in the primary failure zone of an unfilled projectile lowered the survival velocity by 14.7%. Eight longitudinal grooves starting at the same point were less detrimental, lowering the survival velocity compared to the ungrooved configuration 3.6 and 6.9% for unfilled and filled projectiles, respectively. The greater reduction for the filled projectiles is probably associated with the increased hoop stresses in the filled projectiles and the tendency of these projectiles to fracture longitudinally rather than circumferentially.

The survival velocity for unfilled projectiles with longitudinal grooves starting 0.71 inch from the nose was essentially unchanged from the ungrooved value. However, the survival velocity for filled projectiles with longitudinal grooves starting at this same location was reduced by 3.8%. For the filled projectiles the primary bulge region is wider than for the unfilled projectiles and extends past the 0.71 inch location. It is likely that grooves starting slightly more to the rear of the projectile (and outside of the primary failure zone) would not affect survivability.

CONCLUSIONS

This study is a continuation of previous investigations into the effects of shear-control grids on the survivability of impacting warheads. In the previous work shear-control grids were represented by a single circumferential groove. This report is concerned with the effects of longitudinal grooves. For this purpose, small projectiles containing longitudinal grooves were fired against simulated concrete targets. The main conclusions are

1. The influence of longitudinal or circumferential grooves on survival velocity are essentially the same. Grooves in the primary failure zone significantly reduced the survival velocity (although the reduction may be less for longitudinal grooves). Grooves a short distance to the rear of the primary failure zone have little effect on survival velocity.

2. The presence of filler was found to alter the shape of the cavity bulge and also the mode of failure of the projectile. This underscores the importance of including explosive (filler) in finite element analyses of impacting warheads.

3. With regard to warhead design, this work indicates that any detrimental effects of shear-control grids on warhead survivability can be reduced or eliminated completely by keeping the grid out of the primary zone of failure. For penetrators where this zone is relatively small compared to the length of the case, elimination of the grid assures no reduction in survivability while maintaining effective fragmentation control in the major portion of the case.

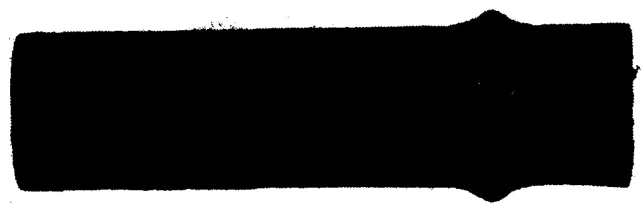
Appendix A
RESULTS OF TEST FIRINGS

(a) 2,380 ft/s

(b) 2,400 ft/s

(c) 2,400 ft/s

FIGURE A-1. Unfilled Projectiles With No Grooves.



(a) 2,370 ft/s

(b) 2,400 ft/s

(c) 2,460 ft/s

FIGURE A-2. Unfilled Projectiles With Longitudinal Grooves Starting 0.46-inch From Nose.

(d) 2,480 ft/s

(e) 2,480 ft/s

FIGURE A-2. (Contd.)

(a) 2,420 ft/s

(b) 2,480 ft/s

(c) 2,510 ft/s

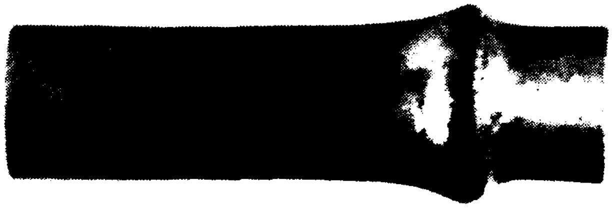
FIGURE A-3. Unfilled Projectiles With Longitudinal Grooves Starting 0.71-inch From Nose.

(d) 2,520 ft/s

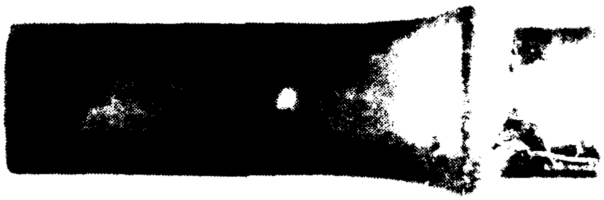
(e) 2,520 ft/s

FIGURE A-3. (Contd.)

(a) 2,275 ft/s



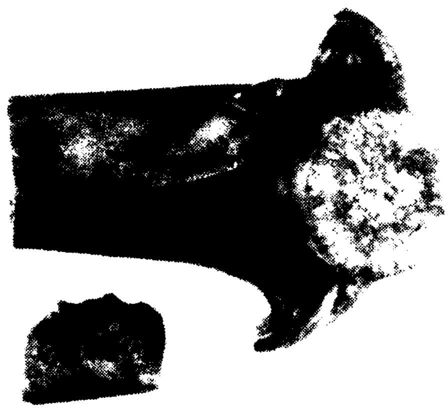
(b) 2,370 ft/s



(c) 2,360 ft/s

FIGURE A-4. Filled Projectiles With No Grooves.

(d) 2,380 ft/s

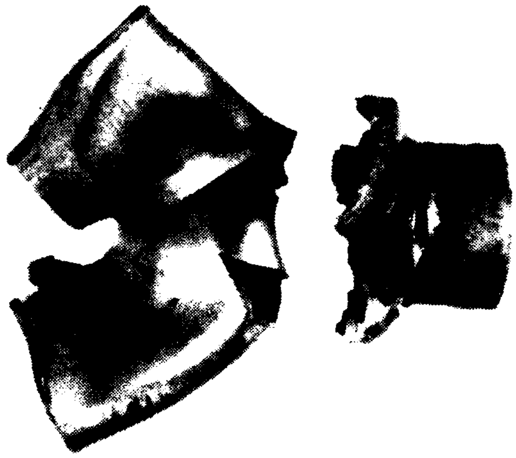


(e) 2,390 ft/s

(f) 2,490 ft/s

FIGURE A-4. (Contd.)

(g) 2,600 ft/s

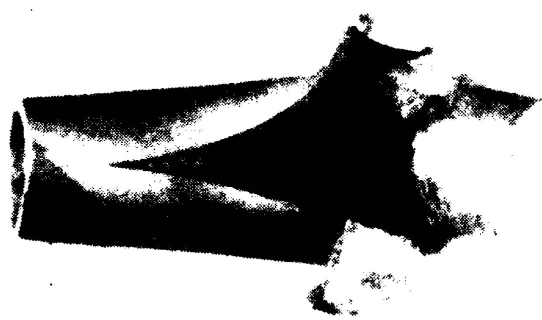


(h) 2,770 ft/s

FIGURE A-4. (Contd.)

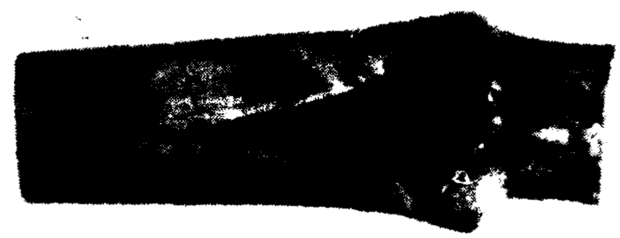
(a) 2,090 ft/s

(b) 2,180 ft/s



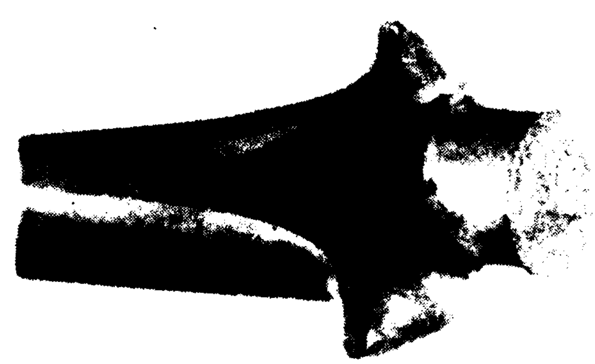
(c) 2,260 ft/s

FIGURE A-5. Filled Projectiles With Longitudinal Grooves Starting 0.48-inch From Nose.



(d) 2,280 ft/s

(e) 2,290 ft/s



(f) 2,360 ft/s

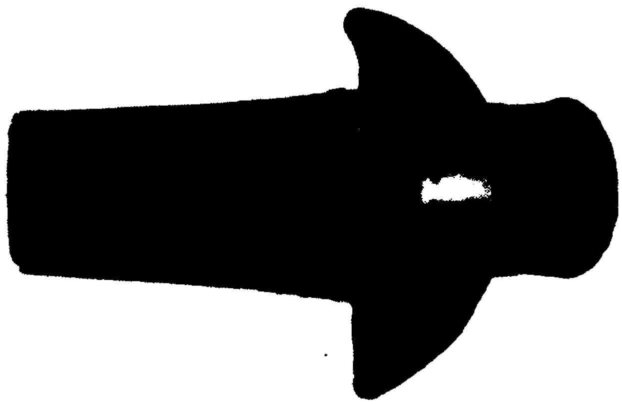
FIGURE A-5. (Contd.)

(a) 2,285 ft/s

(b) 2,220 ft/s

(c) 2,270 ft/s

FIGURE A-8. Filled Projectiles With Longitudinal Grooves Starting 0.71-inch From Nose.



(d) 2,320 ft/s

(e) 2,380 ft/s

FIGURE A-6. (Contd.)

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